Time-dependent Spectroscopy

At BESSRC/XOR, the time-dependent spectroscopy program has been significantly broadened by the development of a time-dependent resonant inelastic scattering technique (RIXS) and a time-dependent x-ray magnetic circular dichroism (XMCD) technique. While time-dependent RIXS experiments probe the influence of electron-phonon coupling on the band structure and carrier dynamics in semiconductors, time-dependent XMCD experiments use element selectivity to probe the switching behavior of magnetic nanoparticles, clusters, and artificial nanostructures on a timescale from 100 ps to μsec. In 2003, basic instrumentation was installed, the proof of principle was demonstrated, and first theoretical modeling for both experiments was performed. The first presentations of results and concepts to the user community presented a strong and vital interest, resulting in various academic and industrial collaborations. The target of these collaborations is to improve the efficiency of light-emitting diodes and semiconductor-based lasers, as well as to increase the understanding of effects in order to allow an increase in the data density of magnetic storage media. (*Contact K. Attenkofer, klaus.attenkofer@anl.gov.*) ❍

Adaptive Optic, Bent-crystal Analyzer for X-ray Fluorescence Spectroscopy

An adaptive optic crystal bender being developed by BESSRC/XOR will improve the energy resolution of ultrafast laser-pump x-ray absorption/fluorescence probe spectroscopy. This device will resolve charge-carrier dynamics within the band structure of semiconductors, such as GaAs. The goal is to reach an x-ray energy resolution of better than 1 eV while collecting a large solid angle of fluorescent radiation under nonbackscattering conditions. So far, about 5 eV of resolution has been demonstrated, which is an improvement over the current state of the art (about 15 eV) for non-backscattering analyzers. The adaptive optic design permits the fine adjustment necessary for energy resolution and, at the same time, permits rapid configuration changes to select different fluorescent lines.

Although this optic was developed for the ultrafast spectroscopy project, the analyzer can benefit all x-ray absorption spectroscopy, particularly near-edge techniques for the measurement of chemical speciation. This applicability makes the analyzer an important instrumental development in its own right.

See: K. Attenkofer, B.W. Adams, and M.A. Beno, "Instrumentation for time-dependent, x-ray resonant Raman scattering," Proceedings of the SRI 2003 conference, to be published.

Author affiliation: Argonne National Laboratory ❍

A Fast CCD Camera for X-ray Photon Correlation Spectroscopy

Charge-coupled device (CCD) development and deployment at IMMY/XOR beamline 8-ID has proceeded on two fronts during the past year or so. A fast, direct-detection CCD camera based on a commercially available SMD (now Dalsa) CCD chip has been developed and deployed. The key feature of the fast CCD camera—the SMD1M60—as a detector for x-ray photon correlation spectroscopy (XPCS) experiments is that it permits the continuous acquisition of images, consisting of individual photon events, at full-frame data rates of up to 60 Hz and 1/16-frame data rates of up to 500 Hz. Thus, it is a simple matter to acquire data with a time resolution of as little as 2 ms, and data from a considerably larger solid angle can be collected if a time resolution of 17 ms is acceptable. In comparison to early-generation detectors, the much greater data rate possible with the SMD1M60 should permit a many-fold increase in the XPCS signal-to-noise ratio in cases where subsecond time steps are needed. In addition, the SMD1M60 is based on an inexpensive, commercially available CCD camera that is lightweight and conveniently transportable. Beyond XPCS, this detector may find application in time-resolved x-ray scattering experiments of all

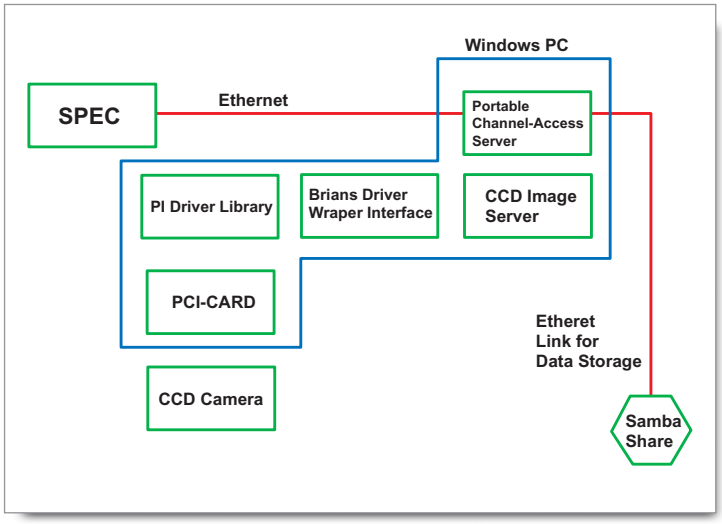

Fig. 1. CCD ImageServer-Yorick-spec control system schematic.

sorts. We have also found it capable of collecting superior small-angle x-ray scattering data. The original camera is available to general users in a collaborative mode. This camera is being duplicated so that it will be fully available to all users.

A Princeton Instruments deep-depletion, direct-detection CCD camera has been successfully integrated into the spec-based and Yorick-based beamline control and data acquisition and analysis system. A control schematic is shown in Fig. 1.

The controls and data acquisition of the CCD camera are implemented within a server-client model. The server software, CCD ImageServer, is a flexible means of acquiring CCD images within the Experimental Physics and Industrial Control System (EPICS) environment. The ImageServer application, running on a Windows-based PC, integrates all functionalities of the CCD camera into a simple API built on top of the EPICS Portable Channel Access Server. By wrapping the native camera-specific interface around a common device interface, the ImageServer application can transparently control cameras from many different manufacturers. On the client side, the beamline control software, Spec, fully controls the CCD camera through the EPICS PV interface and then integrates it into the full suite of 8-ID beamline controls for an experiment.

Data files generated by the CCD camera can be saved either directly to the server or to the (Linux-based) client through Samba-sharing of the directories. Spec provides a user interface to initialize and adjust the CCD parameters but not to display the live images. The EPICS extension EZCA library has been built into Yorick (an interpreted programming language for data analysis and image processing similar to IDL) so that Yorick displays real-time CCD images on the client. The Yorick user interface also provides image-processing utilities, such as camera contrast adjustments, image zooming, image dark subtraction, and image calculations. Since its deployment in late November 2003, the new camera control system has been used successfully by both IMMY/XOR members and general users. *(Contact S. Mochrie, simon.mochrie@yale.edu)* ❍

"Coherent" XPCS Analysis Code

A significant recent achievement has been the development and deployment of faster, more user-friendly x-ray photon correlation spectroscopy (XPCS) data reduction software, which is now installed at IMMY/XOR beamline 8-ID-I as a standard part of the XPCS package.

This GNU-public-licensed software package, called "coherent," includes several key features that greatly facilitate XPCS experiments and the 8-ID general-user program. Specifically, among many other features, it allows the graphic creation of masks for determining the data that should and should not be included in analysis; allows bad charge-coupled device frames to be dropped; automatically reads in relevant parameters based on the beamline configuration at the time of data acquisition (and allows them to be easily modified if necessary); and allows the experimentally determined autocorrelation decay functions to be fit to a variety of physically relevant functional forms. Perhaps most important, it achieves all of this in a manner that inexperienced users have found particularly easy to learn and experienced users have found straightforward to modify as needed for advanced analysis.

Outside of its use by IMMY/XOR members, the software—which has been subject to ongoing refinement since installation in July 2002 — has by now been employed by a number of research groups at universities (California, San Diego, Northern Illinois, SUNY Stony Brook) and user facilities Intense Pulsed Neutron Source, National Synchrotron Light Source) for their XPCS experiments at 8-ID. *(Contact A. Sandy, asandy@aps.anl.gov)* ❍

Zone-Plate Microfocusing for XPCS

Implementation of the IMMY/XOR 8-ID-E shutter has allowed development of the 8-ID-E side station without disturbing the fully operational general-user program at 8-ID-I. In this context, several important upgrades to 8-ID-E have been recently completed. One such improvement was vacuum integration of the 8-ID-E shutter with the transmission side-station monochromator. This significantly increased the flux delivered to station 8-ID-E. More significant has been the development and deployment at 8-ID-E of a micromotion xyz sample stage capable of submicron resolution. The stage motion is driven by Picomotors™ mounted on three orthogonal axes, each controlled in a feedback loop to laser optical position encoders. These encoders allow for absolute stage motion to submicron precision over several inches of travel. The design is simple, efficient, and less costly than comparable off-the-shelf units. However, relying on software feedback between two independent devices to achieve precise motion made integration of the setup into the control system nontrivial.

The stage was installed on a three-circle diffractometer to allow microprobe diffraction measurements with a zone-plate-focused x-ray beam. This geometry essentially makes possible independent crystallographic measurements of microstructures within a sample, retrieving information about local lattice constants, lattice orientation, and disorder.

Preliminary experiments mapping ferroelectric domains in $BaTiO_3$ indicate reliable stage motion to less than 0.1 μm, allowing users to successfully exploit the spatial resolution of the focused x-ray beam (vertical spot size ~0.8 μm). The stage has also been used recently by the collaborative general-user research groups of Y. Chu and I. McNulty. *(Contact M. Sutton, mark@physics.mcgill.ca)* ❍

Measuring the Microstructure of Processed Materials

The properties of many materials depend on microstructure as well atomic structure, which explains why so many materials processing methods focus on changing microstructure. Experimenters can study the microstructure of materials using dynamic light scattering, a method that uses coherent visible light. Information provided by this method, however, is limited by the wavelength of the light used. In order to study microstructure at shorter lengths, researchers from McGill University and UMR, Le Centre National de la Recherche Scientifique (CNRS), are extending the method into the x-ray regime, developing a scattering method called x-ray intensity fluctuation spectroscopy (XIFS). They show how it can be used to study systems that are not in equilibrium.

Although XIFS is new, other (incoherent) x-ray diffraction techniques have been used for decades for applications such as crystallography. XIFS, however, requires that the x-ray source be coherent and intense enough to provide a good diffraction "image" at the time scales of interest (which can be as short as milliseconds). Therefore, the researchers used the 8-ID beamline at IMMY/XOR sector 8 to demonstrate this method of studying microstructure.

XIFS exploits an effect of coherent radiation: speckle. When coherent light scatters diffusely off a disordered material, each spot in the image is the sum of many rays of scattered light, each with a different phase. Bright spots occur where the superposition of the rays is constructive, while dark spots occur where the rays add destructively. The entire image is speckled with a dark and light pattern.

This speckle pattern is a projection of the Fourier transform of the scattering volume. If the diffracting sample fluctuates over time, then the speckle intensities change as well. XIFS extracts information on the sizes and motions of light-scattering particles from the changes in time and space of the speckle pattern. Particles suspended in liquids undergo Brownian motion; hence, their position fluctuates over time and therefore so does the speckle pattern. The group measured the intensity fluctuations of the speckle pattern created by gold colloids in polystyrene (see Fig. 1). By measuring the way diffraction intensity changes over time, the researchers discerned changes in density over time.

This experiment demonstrates the possibility of measuring two-time correlation functions. Instead of averaging over time to obtain good statistics (as measurements of equilibrium systems often do), the researchers used an area detector to measure many speckles at the same time to obtain good statistics for a full two-time correlation function. For a system in equilibrium, such as the example mentioned above, the correlation between the measurement and density depends only on the difference in time between the measurements, as shown in the figure.

Many interesting materials, however, are not in equilibrium. A material that has undergone some sort of material processing in order to change its properties is not at equilibrium. Methods often used for measuring systems in equilibrium don't work for these materials, partly because they assume that the average scattered intensity remains constant.

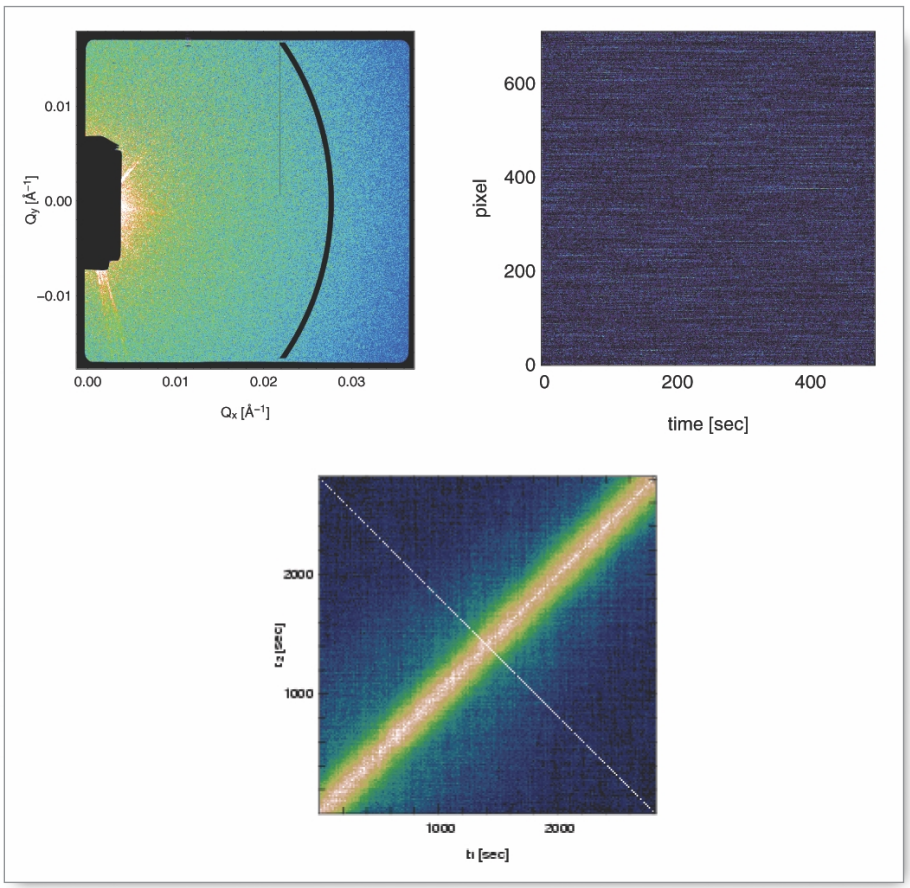

Fig. 1. Top left: Intensity of coherent x-ray small angle scattering from a system in equilibrium (6.0-nm Au particles in polystyrene). False color image uses brightness to indicate intensity. Black block on the left is the stop for the unscattered beam of x-rays. Black arc indicates the pixels sampled over time in the image at top right. Top right: Time evolution of an arc of pixels. Although all pixels share an average intensity, the intensity of the scattered x-rays at each individual pixel fluctuates over time due to the Brownian motion of the scattering particles. Bottom: By correlating the two rows in the top right image corresponding to the times t_1 and t_2, researchers obtained the two-time correlation function $C(t_1, t_2)$ for this particular wave vector. Because this system is in equilibrium, the correlation function depends only on t_1-t_2, as shown by the contours being parallel to the diagonal. The quality of the data demonstrate that this analysis can be used to measure two time correlation functions even for nonequilibrium systems.

This work demonstrates the method with an example: the phase separation of an aluminum-lithium alloy cooled to just below its critical temperature, where the microstructural changes that occur happen on a timescale that can be measured by this method. The sample was prepared by heating it above its critical temperature to mix the metals and then quickly cooling it from 475°C to room temperature, which "freezes in" this homogeneous structure. Then it was heated and held at 220°C, a temperature at which diffusion is significantly faster and the material starts to unmix. In this system, the two-time correlation function depends on both the time difference and the time since the temperature was raised. The good agreement between these measurements and a theoretical model of phase separation give more evidence of the validity of dynamical scaling. Work is in progress on using this technique for other systems. ❍

See: M. Sutton[1], K. Laaziri[1], F. Livet[2], and F. Bley[2], "Using coherence to measure two-time correlation functions," Opt. Express **11**, 2268-2277 (22 September 2003).
Author affiliations: [1]McGill University, [2]LTPCM-ENSEEG-INPG, UMR-CNRS

Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-Eng-38.

Mapping Microelectronic Circuits with X-rays

Thanks to the skill of chip designers in squeezing more and more components into every corner of a silicon wafer, microcircuits have historically been doubling in processing power nearly every 18 months. This trend has been made possible by photolithographic technologies capable of creating smaller and smaller structures. To reach the next generation of chip manufacturing, however, features smaller than 100 nm will have to be fabricated. Mass producing such structures also means rapidly measuring them and characterizing their quality. But current methods, such as electron microscopy and atomic force microscopy, all face profound challenges in sub-100-nm technological applications. Now, a team of researchers at the National Institute of Standards and Technology (NIST), ExxonMobil Research and Engineering, the Shipley Company, and Argonne National Laboratory are using x-ray scattering techniques to determine the shape and quality of photolithographic features with nanometer resolution.

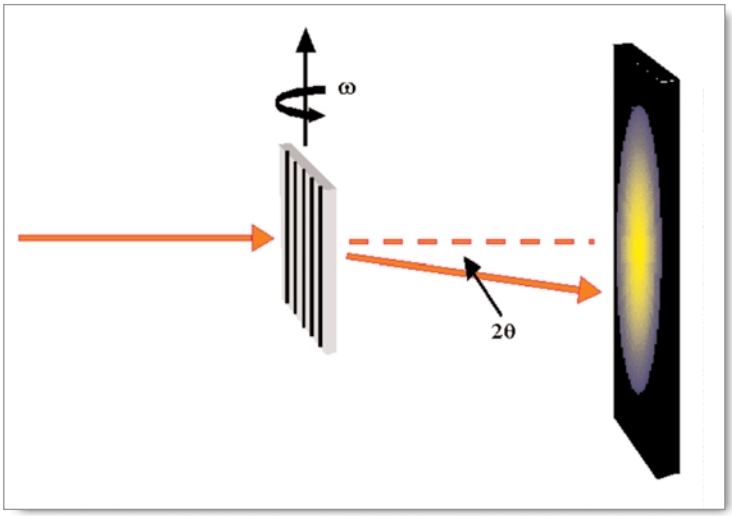

Fig. 1. Configuration of experiments for small-angle x-ray scattering. X-ray beam from the APS source hits the sample at normal incidence. Scattering x-rays are collected at 2θ downstream of beamline at different rotation angles ω.

Optical scattering has become an established tool in developing microfabrication methods as well as in characterizing structures on the process line. But as feature sizes decrease, the comparatively long wavelengths of light severely limit useful measurement. By moving to shorter x-ray wavelengths, the smaller structures envisioned for future generations of integrated circuits can be probed. In addition, the relatively weaker interaction of x-rays and most materials allows a wider range of materials (including metals) to be studied compared with the range available via light scattering.

To explore the possibility of employing x-ray scattering for feature dimension determination, the research team used samples of polymer photoresist arranged in a grating pattern on a silicon substrate. This kind of test pattern is a standard method of calibrating and evaluating photoresist quality and imaging conditions. The gratings used in these experiments were fabricated with a nominal line width of 180 nm. Small-angle x-ray scattering (SAXS) was carried out at the CMC-CAT beamline 9-ID at the APS, with the source beam directed onto the grating at normal incidence (Fig. 1). Transmission scattered x-rays were collected downstream of the source by means of a charge-coupled device camera 543 cm from the sample. The x-ray wavelength of 0.095 nm was selected to have sufficiently low absorption by the silicon substrate while maintaining a reasonable instrument resolution.

X-ray diffraction from the grating produced a linear pattern of spots on the detector for different rotation angles of the sample. This diffraction pattern is fitted to an expression based on a group of lines with a trapezoidal cross section. The width of the grating lines is then extracted from the data fit, as is the sidewall angle of the grating lines. For the three test gratings used (critical dimension ~180 nm), line widths of 171, 159, and 167 nm were measured with resolution (3 σ) on the order of 3 to 4 nm. Sidewall angles for the same specimens were 88.2°, 87.9°, and 88.5°. These results were in agreement with direct measurements made by scanning electron microscopy.

The results demonstrate the usefulness of SAXS in characterizing patterns created by photolithography. Data collection

for each sample was completed in a time on the order of seconds, making the method attractive from a processing standpoint. Through careful selection of x-ray wavelength, structures made from many different materials can be resolved, while future studies will examine samples with sub-100-nm feature sizes. With the extremely short wavelength x-rays available at third-generation synchrotrons such as the APS, SAXS could potentially become a valuable tool for the fabrication of next generation of microelectronics. ❍

See: R.L. Jones[1], T. Hu[1], E.K. Lin[1], W.-L. Wu[1], R. Kolb[2], D.M. Casa[3], P.J. Bolton[4], and G.G. Barclay[4], "Small angle x-ray scattering for sub-100 nm pattern characterization," Appl. Phys. Lett. **83** (19), 4059-4061 (10 November 2003).

Author affiliations: [1]NIST, [2]ExxonMobil Research and Engineering Company, [3]CMC-CAT, [4]Shipley Company, LLC

This work was funded in part by the Defense Advanced Research Projects Agency Advanced Lithography Program under Contract No. N66001-00-C-8083. Additional funding was provided by the NIST Office of Microelectronic Programs. R.L.J is supported by a NIST National Research Council postdoctoral fellowship. Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-Eng-38.

Advances in Quantitative X-ray Tomography

X-ray phase-contrast imaging—in which information about the structure and composition of an object is obtained from the refractive interaction of x-rays with matter—is advancing rapidly. One goal is to use x-ray phase tomography to create three-dimensional (3-D) images of an object with negligible absorption. Using the brilliant x-ray beams from the APS, researchers from the University of Melbourne and Argonne National Laboratory achieved that goal by making tomographic x-ray phase reconstructions of an atomic force microscope (AFM) tip at a spatial resolution of 900 nm. The resulting 3-D images yield a quantitative measurement of the real part of the refractive index. This work opens the door for full 3-D imaging of the complex refractive index with submicron spatial resolution.

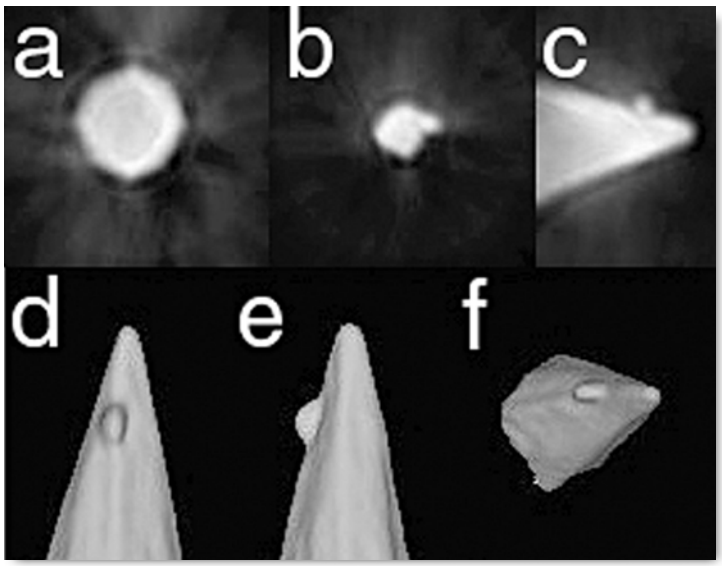

Fig. 1. Quantitative 3-D reconstructions of the real part of the refractive index of the AFM tip. (a) Horizontal slice through the tip. (b) Horizontal slice including the spherical bump. (c) Vertical slice. (d-f) Volume renderings.

Driving advances in this x-ray technology are third-generation synchrotrons, such as the APS, which offer significantly greater coherent x-ray flux. Researchers previously demonstrated quantitative phase two-dimensional imaging at the APS [1]. Building upon that research, they used the same arrangement for this tomographic study. The microscope was assembled at XOR beamline 2-ID-B at the APS. The sample was a commercially available AFM tip (Silicon-MDT Ltd., Moscow, Russia).

A highly coherent beam of 1.83-keV x-rays, defined by a 20-μm-diameter aperture, was passed through the sample. A 90-μm-diameter, 110-nm-thick Ni zone plate with an outer zone width of 45 nm was used to image the sample. The x-rays were propagated in vacuum to a backside-illuminated 1024 × 1024-pixel charge-coupled device camera with a 24 μm pixel size. The sample was magnified to approximately 160 times its actual size. Phase data for each projection were obtained, and the data were reconstructed into a 3-D image.

The absorption contrast of the silicon AFM tip sample was very small, yielding a very poor reconstruction by conventional x-ray microtomography reconstruction methods. The phase contrast is, however, significant at this key energy. The finest fringe structure visible in the projection data is consistent with an instrumental spatial resolution of 230 nm. Figure 1 shows examples of the resulting 3-D phase reconstructions. Figures 1(a) and 1(b) represent slices through the tip in the horizontal direction, whereas Fig. 1(c) depicts a slice of the reconstruction through the vertical direction.

In Figs. 1(b) and 1(f), a spherical bump, measuring 900 nm in diameter, is clearly visible. The faceted structure in Fig. 1(a) is even more evident in Figs. 1(d)–1(f). The AFM tip was not perfectly sharp, so it is possible that the actual resolution may be better than 900 nm, but no features at a smaller scale were seen. On the basis of sinograms taken from the tomographic data sets for both phases, the group was able to confirm that the facets are a genuine feature of the tip. In fact, such a structure is typical of the manufacturing process used to etch crystalline AFM tips [2]. The researchers also compared the known

composition of the AFM sample tip with the tabulated value at this energy. They found that the experimental value agreed with the tabulated value to well within the experimental error, confirming that a high-resolution quantitative map of the real part of the refractive index was obtained.

This work demonstrated quantitative imaging of the phase distribution of a weakly absorbing sample at a 3-D resolution of least 900 nm. It also yielded an accurate measurement of the real part of the sample refractive index. The next step is to obtain a full measurement of the 3-D complex refractive index. ❍

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[1] B.E. Allman, P.J. McMahon, J.B. Tiller, K.A. Nugent, D. Paganin, A. Barty, I. McNulty, S.P. Frigo, Y.X. Wang, and C.C. Retsch, J. Opt. Soc. Am. A **17**, 1732 (2000).

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Author affiliations: [1]University of Melbourne, [2]Argonne National Laboratory

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Full-field Imaging Methods

Fast X-ray Microtomography

The microtomography system at 2-BM offers near video-rate acquisition of tomographic data combined with automatic data acquisition, reconstruction, and visualization. Users can acquire up to 720 tomographic projections (1024 pixels × 1024 pixels) at 0.25° angular increments in less than 5 min. The data are reconstructed by a dedicated 32-node, 1-GHz Intel PIII computer cluster with 2 TB of distributed hard disk. Rendered three-dimensional (3-D) images of the sample are displayed on a workstation at the experimental station within 3 min of acquisition of the last projection. Low-resolution (512 pixels × 512 pixels) images are available within 50 s. The raw data are automatically backed up on tape and DVD, with the analyzed data ready for distribution within 15 minutes. At its maximum rate, the system can collect and analyze hundreds of samples in a 24-h experiment. This year, the charge-coupled device camera used to record the projections was mounted on a 1.2-m-long motorized rail aligned with the beam, enabling the sample-to-scintillator distance to be optimized for either absorption or phase contrast. A sample changer was also integrated into the system for automatic loading of up to 70 samples. The instrument is mounted on a dedicated, motorized, optical table that can easily slide in and out of the beam while keeping the components aligned. This configuration has greatly reduced the time required to switch between experiments at 2-BM.

See: S.R. Stock, K.I. Ignatiev, T. Dahl, A. Veis, and F. DeCarlo, "Three-dimensional microarchitecture of the plates (primary, secondary and carinar process) in the developing tooth of Lytechinus variegatus revealed by synchrotron x-ray absorption microtomography (microCT)," J. Struct. Biol. **144**, 282-300 (2003).

Structural Characterization of Combinatorial Materials

Combinatorial approaches play an increasingly important role in a wide range of disciplines as a method for high-throughput materials exploration. In particular, thin-film combinatorial samples can be fabricated with compositional profiles across a substrate so that phase diagrams and properties, especially phase boundaries and transitions, can be systematically mapped out and studied as a continuous function of composition. Reliable and rapid quantitative structural characterization has been a major bottleneck for this type of research, owing in part to the insufficient brilliance of laboratory x-ray sources. To eliminate this bottleneck, instrumentation and techniques have been developed at XOR 2 for combinatorial samples, in which x-ray diffraction and fluorescence measurements can be carried out in parallel using by Kirkpatrick-Baez focusing optics in a common sample coordinate system.

See: F. Tsui[1], L. He[1], L. Ma[1], A. Tkachuk[2], Y.S. Chu[2], K. Nakajima[3], and T. Chikyow[3], "Novel germanium-based magnetic semiconductors," Phys. Rev. Lett. **91**, 177203 (2003).

Time-resolved Full-field X-ray Diffraction Imaging

The high brilliance of APS bending magnet sources coupled with high-resolution CCD cameras make it possible to obtain time-resolved diffraction images down to submicrometer length scales. Since the diffraction contrast from the sample is obtained with a single exposure, the full-field imaging method is especially suited for investigation of dynamic systems. This technique was applied at XOR 2 to investigate nucleation and growth of ferroelectric domains in $BaTiO_3$ single crystals. *(Contact Y. Chu (ychu@aps.anl.gov)*

Scanning Fluorescence X-ray Microscopy

The x-ray fluorescence microprobes at XOR sector 2 operate in a mode in which full fluorescence spectra are acquired at every image position to maximize the amount of information extracted from the specimen. Dedicated software has also been developed for precise quantification of chemical elements in both single pixels and across whole images. Advanced procedures, such as cluster analysis and principal component analysis, can be applied to the acquired data sets to detect and visualize correlations that might not otherwise be apparent.

The beam stability during energy scans in hard x-ray absorption near-edge spectroscopy (XANES) experiments at 2-ID-D was improved considerably. By running the monochromator in channel-cut mode, beam drift was reduced to the size of the beam (0.25 μm). This made it possible to perform micro-XANES measurements on ultrafine (<50 nm) iron impurities in polysilicon solar cells, revealing that the precipitates are most likely $FeSi_2$.

See: T. Buonassisi, M. Heuer, O.F. Vyvenko, A.A. Istratov, E.R. Weber, Z. Cai, B. Lai, T.F. Ciszek, and R. Schindler, "Applications of synchrotron radiation x-ray techniques on the analysis of the behavior of transition metals in solar cells and single-crystalline silicon with extended defects," Physica B **340-342**, 1137-1141 (2003), and Z.H. Levine, S. Grantham, D.J. Paterson, I. McNulty, I.C. Noyan, and T.M. Levin, "Imaging material components of an integrated circuit interconnect," J. Appl. Phys. **95**, 405-407 (2004).

X-ray Nanodiffraction

Until recently, the reciprocal space characterization of nanomaterials with x-rays was limited to the measurement of their average properties because a large number of nano-objects had to be probed in order to produce a measurable signal. Improvements in hard x-ray sources, focusing optics, and diffraction techniques have recently enabled this limitation to be overcome. A new instrument at XOR beamline 2-ID-D integrates high-efficiency zone-plate lenses and a six-circle diffractometer to probe a broad range of reciprocal space with an intense, nanofocused x-ray beam. The necessary mechanical stability was achieved by use of vibration-isolation mechanisms and direct support of the diffractometer during data acquisition. The measured effective focal spot size is less than 200 nm. The typical measured photon flux density on the sample is 10^5 photons/s/nm^2/0.01% BW at x-ray energies of 6 keV to 12 keV, corresponding to 10^7 photons/s incident on 10 nm × 10 nm nano-object. *(Contact Z. Cai, cai@aps.anl.gov)*

Differential Phase-contrast Microscopy and On-the-Fly-Scanning

Thin, light specimens, such as biological cells and subcellular organelles, are nearly transparent to x-ray beams with photon energies above ~1 keV. However, at higher x-ray energies, the real part of the complex index of refraction can be several orders of magnitude larger than the imaginary part, especially for the light elements. This effect can be exploited to image low-density sample structures by differential phase contrast (DPC) x-ray microscopy. Differential phase-contrast can also be used in parallel with x-ray fluorescence detection for trace element mapping. Other advantages of this approach include simultaneous collection of bright field, dark field, and phase contrast signals; filtration of beam intensity variations; and compatibility with fast-scan methods. To develop DPC capability, an eight-element segmented detector was incorporated into the scanning x-ray microscopes at XOR beamlines 2-ID-B and 2-ID-E (Fig. 1). *(Contact D. Paterson (paterson@aps.anl.gov) and S. Vogt (vogt@aps.anl.gov)* ❍

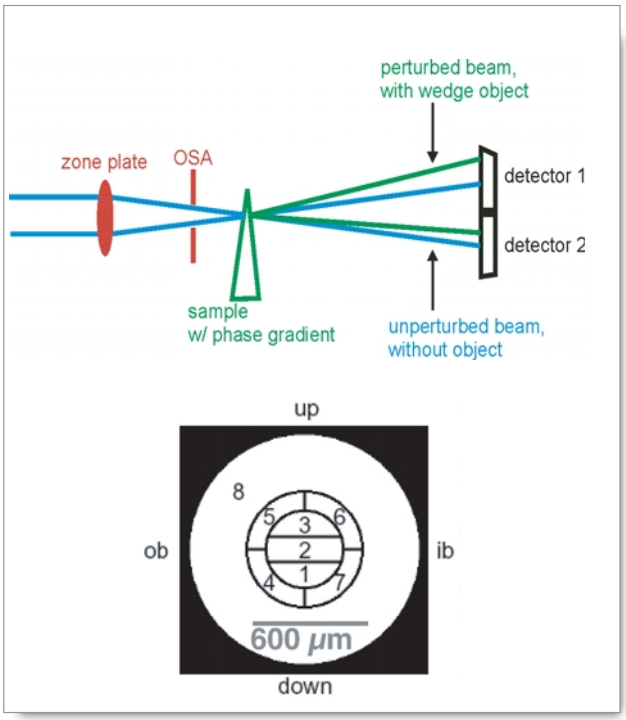

Fig. 1. Zone-plate scanning microscope (top) and segmented detector for DPC measurements.